US009207076B2

(12) **United States Patent**
Chang et al.

(10) **Patent No.: US 9,207,076 B2**
(45) **Date of Patent: Dec. 8, 2015**

(54) **COMPUTING DEVICE AND METHOD FOR DETERMINING RICOCHET VECTORS OF A PROBE OF A COORDINATE MEASURING MACHINE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 527 days.

(21) Appl. No.: **13/710,661**

(22) Filed: **Dec. 11, 2012**

(65) **Prior Publication Data**

US 2013/0162815 A1 Jun. 27, 2013

(30) **Foreign Application Priority Data**

Dec. 21, 2011 (CN) 2011 1 0432958

(51) **Int. Cl.**

G01C 15/00	(2006.01)
G01B 21/04	(2006.01)
G01B 5/008	(2006.01)
G06F 15/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G01C 15/00*** (2013.01); ***G01B 5/008*** (2013.01); ***G01B 21/045*** (2013.01); ***G06F 15/00*** (2013.01)

(58) **Field of Classification Search**

CPC G01B 5/008; G01B 7/008; G01B 21/04; G01B 21/045; G01C 15/00; G06F 15/00

USPC 33/503, 504, 556, 559; 702/94, 95

See application file for complete search history.

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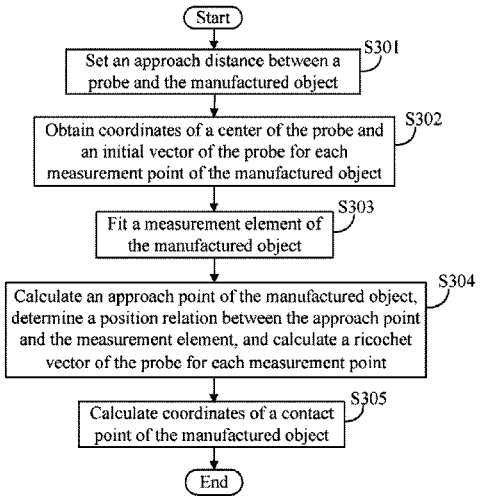
(57) **ABSTRACT**

In a method for determining ricochet vectors of a probe of a coordinate measuring machine (CMM) using a computing device, the computing device sets an approach distance between the probe and a manufactured object. Coordinates of a center of the probe and an initial vector of the probe for each measurement point of the manufactured object are obtained when the probe is manually operated to measure the manufactured object. A measurement element of the manufactured object is fit according to all measurement points of the manufactured object. For each measurement point, an approach point of the manufactured object is calculated, a position relation between the approach point and the measurement element of the manufactured object is determined, and a ricochet vector of the probe is calculated according to the position relation.

15 Claims, 4 Drawing Sheets



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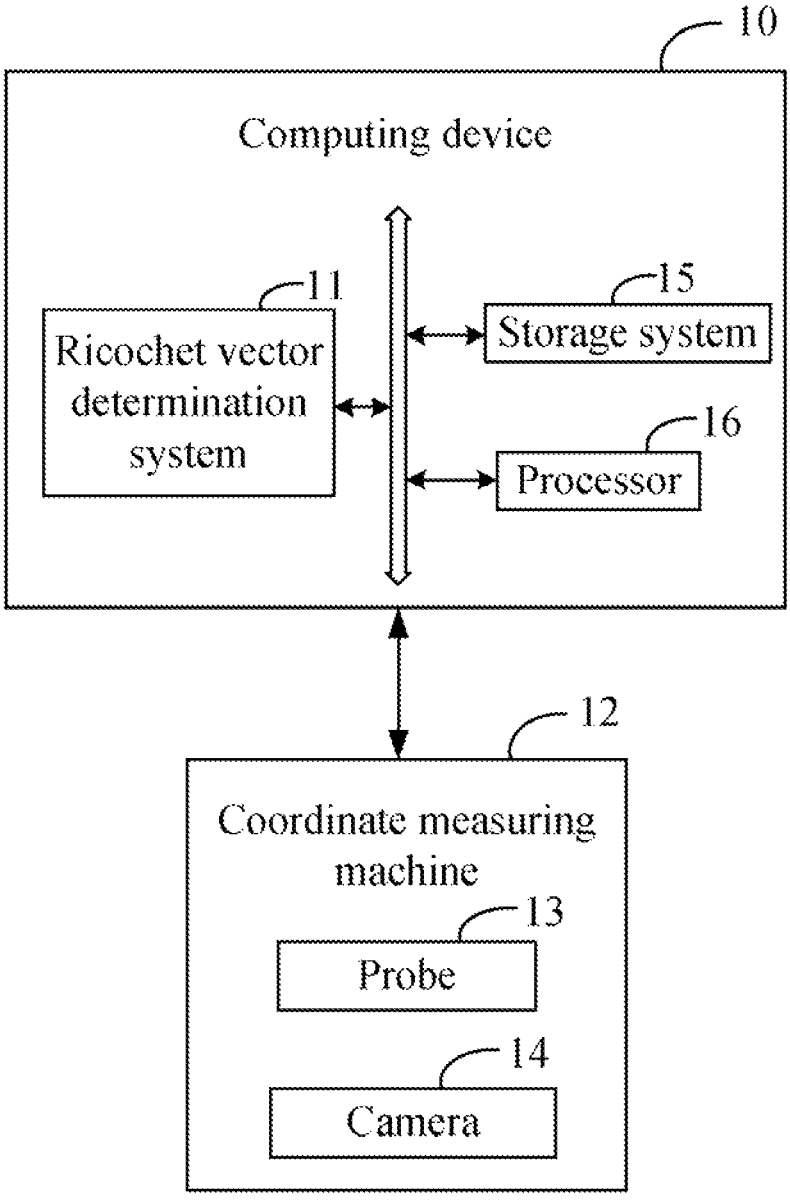
10
Computing device
11
Ricochet vector determination system
15
Storage system
16
Processor
12
Coordinate measuring machine
13
Probe
14
Camera

FIG. 1

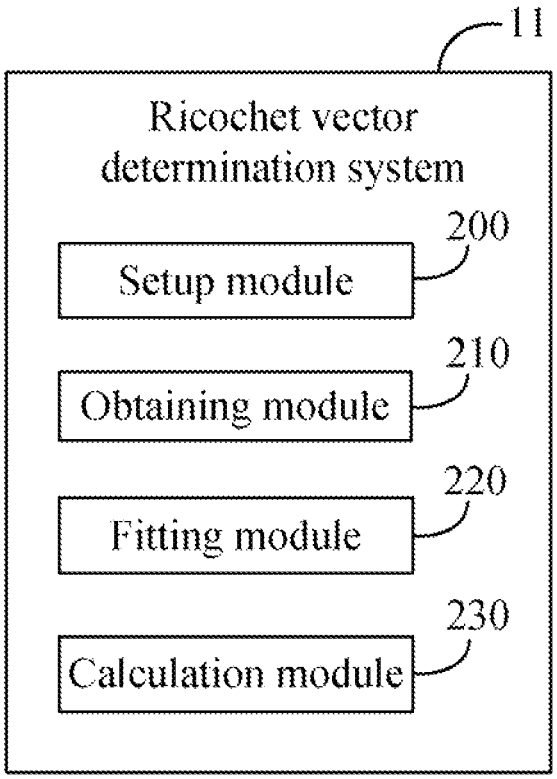
11
Ricochet vector determination system
200
Setup module
210
Obtaining module
220
Fitting module
230
Calculation module

FIG. 2

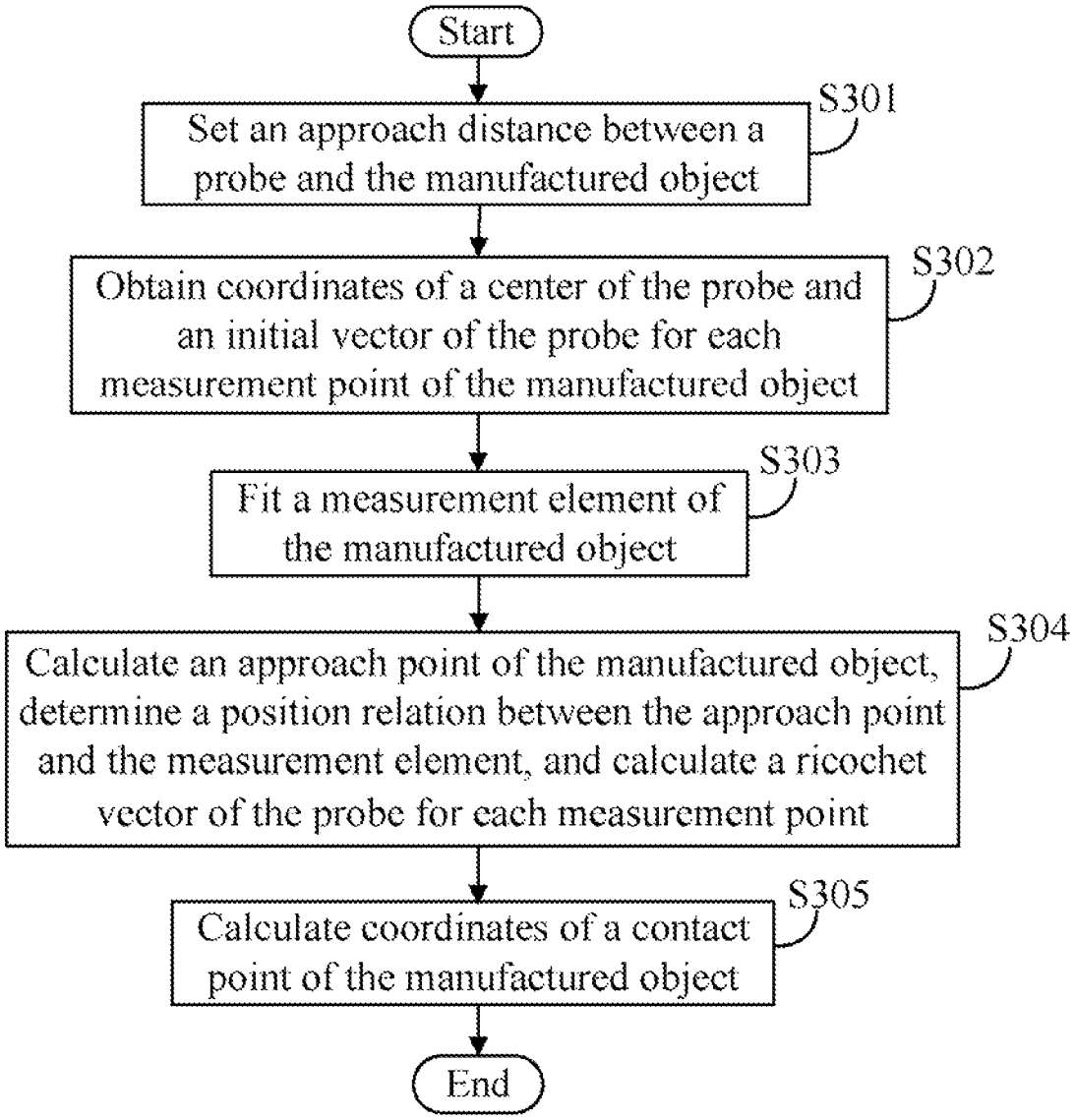
Start
Set an approach distance between a probe and the manufactured object
S301
Obtain coordinates of a center of the probe and an initial vector of the probe for each measurement point of the manufactured object
S302
Fit a measurement element of the manufactured object
S303
Calculate an approach point of the manufactured object, determine a position relation between the approach point and the measurement element, and calculate a ricochet vector of the probe for each measurement point
S304
Calculate coordinates of a contact point of the manufactured object
S305
End

FIG. 3

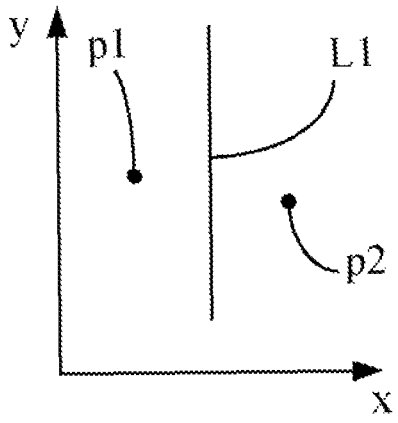

FIG.4

COMPUTING DEVICE AND METHOD FOR DETERMINING RICOCHET VECTORS OF A PROBE OF A COORDINATE MEASURING MACHINE

BACKGROUND

1. Technical Field

The embodiments of the present disclosure relate to measuring manufactured objects, and particularly to a computing device and method for determining ricochet vectors of a probe of a coordinate measuring machine.

2. Description of Related Art

Coordinate measuring machines (CMMs) are widely used in industry to measure manufactured objects (e.g., metal castings). A CMM includes a probe used to contact with surfaces of the manufactured object, to obtain coordinates of the surfaces of the manufactured object. When the CMM performs automatic measurement of the manufactured object, contact points of the manufactured object are determined according to ricochet vectors of the probe. The ricochet vectors indicate directions in which the probe moves towards or away from the manufactured object. If the ricochet vectors are found to be incorrect, the contact points of the manufactured object may be inaccurate, so that measurement results of the manufactured objects may be unreliable.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is one embodiment of an application of a computing device.

FIG. **2** is a block diagram of one embodiment of function modules of a ricochet vector determination system in FIG. **1**.

FIG. **3** is a flowchart of one embodiment of a method for determining ricochet vectors of a probe of a coordinate measuring machine using the computing device in FIG. **1**.

FIG. **4** illustrates one embodiment of calculating ricochet vectors of a probe, where a measurement element of a manufactured object is a line on an XY plane and a slope of the line does not exist.

DETAILED DESCRIPTION

The disclosure is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

In general, the word "module", as used herein, refers to logic embodied in hardware or firmware, or to a collection of software instructions, written in a programming language, such as, Java, C, or assembly. One or more software instructions in the modules may be embedded in firmware, such as in an erasable programmable read only memory (EPROM). The modules described herein may be implemented as either software and/or hardware modules and may be stored in any type of non-transitory computer-readable medium or other storage device. Some non-limiting examples of non-transitory computer-readable media include CDs, DVDs, BLU-RAY, flash memory, and hard disk drives.

FIG. **1** is one embodiment of an application of a computing device **10**. In the embodiment, the computing device **10** is connected to a coordinate measuring machine (CMM) **12**. The CMM **12** includes a probe **13** and a camera **14**. The probe **13** contacts surfaces of a manufactured object (not shown in FIG. **1**) when the CMM **12** performs measurement of the manufactured object. The manufactured object may be a molded part, such as a metal casting, for example. When the probe **13** moves to measure the manufactured object, the camera **14** focuses on the manufactured object. According to a focus position of an optical lens of the camera **14**, coordinates of a center point of the probe **13** are obtained.

The computing device **10** includes a ricochet vector determination system **11**, a storage system **15**, and at least one processor **16**. The ricochet vector determination system **11** is used to determine ricochet vectors of the probe **13**. The ricochet vectors indicate directions in which the probe **13** moves towards or away from the manufactured object when the CMM **12** performs automatic measurement of the manufactured object. In one embodiment, a magnitude of each of the ricochet vectors is **1**. The storage system **16** may be a dedicated memory, such as an EPROM, a hard disk drive (HDD), or flash memory. In some embodiments, the storage system **16** may be an external storage device, such as an external hard disk, a storage card, or a data storage medium.

FIG. **2** is a block diagram of one embodiment of function modules of the ricochet vector determination system **11** in FIG. **1**. The ricochet vector determination system **11** includes a setup module **200**, an obtaining module **210**, a fitting module **220**, and a calculation module **230**. The modules **210-230** may comprise computerized code in the form of one or more programs that are stored in the storage system **15**. The computerized code includes instructions that are executed by the at least one processor **16**, to provide the aforementioned functions of the ricochet vector determination system **11**. A detailed description of the functions of the modules **210-230** is given in reference to FIG. **3**.

FIG. **3** is a flowchart of one embodiment of a method for determining ricochet vectors of the probe **13** using the computing device **10** in FIG. **1**. Depending on the embodiment, additional steps may be added, others removed, and the ordering of the steps may be changed.

In step S**301**, the setup module **210** sets an approach distance between the probe **13** and the manufactured object, and stores the approach distance into the storage system **15**. The probe **13** may move towards the manufactured object at a predetermined speed within the approach distance.

In step S**302**, the obtaining module **220** obtains coordinates of a center of the probe **13** and an initial vector of the probe **13** for each measurement point of the manufactured object when the probe **13** is manually operated to measure the manufactured object. The probe **13** contacts the manufactured object at each measurement point when the probe **13** is manually operated to measure the manufactured object. In one example, five un-collinear measurement points are selected when the probe **13** is manually operated to measure a sphere. The initial vector of the probe **13** indicates a direction in which the probe **13** moves towards the measurement point in manual measurement. In this embodiment, the obtaining module **220** obtains the coordinates of the center of the probe **13** for the measurement points according to the focus position of the optical lens of the camera **14**.

In step S**303**, the fitting module **230** fits a measurement element of the manufactured object according to all measurement points of the manufactured object. The measurement element may be a line, a plane, a circle, an arc, an ellipse, or a sphere. In one example, the fitting module **230** fits a sphere of the manufactured object according to the five un-collinear measurement points. In one embodiment, the fitting module **230** uses a method of least squares, in conjunction with the quasi-Newton iterative algorithm, to fit the measurement element of the manufactured object.

In step S304, for each measurement point, the calculation module **230** calculates an approach point of the manufactured object according to the approach distance and a corresponding initial vector of the probe **13**, determines a position relation between the approach point and the measurement element of the manufactured object, and calculates a ricochet vector of the probe **13** according to the position relation. A distance between the measurement point and a corresponding approach point is equal to the approach distance. A direction from the corresponding approach point to the measurement point is in the same direction as a direction of a corresponding initial vector of the probe **13**. When the CMM **12** performs automatic measurement of the manufactured object, the probe **13** moves towards the measurement point in an opposite direction of the ricochet vector and bounces off the measurement point in the direction of the ricochet vector. The calculation module **230** further stores the ricochet vector of the probe **13** into the storage system **15**.

In one example with respect to FIG. **4**, the measurement element of the manufactured object is a line on an XY plane. If a slope of the line does not exist and the approach point of the manufactured object is located on the left side of the line (e.g., a point labeled "p**1**"), the ricochet vector of the probe **13** is (−1, 0, 0). If the slope of the line does not exist and the approach point of the manufactured object is located on the right side of the line (e.g., a point labeled "p**2**"), the ricochet vector of the probe **13** is (1, 0, 0). If the slope of the line exists and a direction vector of the line is (a, b, 0), where a and b are the distance along the x and y coordinates respectively, the ricochet vector of the probe **13** is (i, j, 0), where i and j are calculated according to equations $i^2+j^2=0$ and $a*i+b*j=0$. If the approach point of the manufactured object is located on the upper side of the line and the slope of the line is less than 0, or if the approach point of the manufactured object is located on the down side of the line and the slope of the line is larger than 0, i and j are calculated as follows:

$$i = \sqrt{\frac{b^2}{a^2+b^2}}$$

and

$$j = -\frac{a}{b} * i.$$

If the approach point of the manufactured object is located on the upper side of the line and the slope of the line is larger than 0, or if the approach point of the manufactured object is located on the down side of the line and the slope of the line is less than 0, i and j are calculated as follows:

$$i = -\sqrt{\frac{b^2}{a^2+b^2}}$$

and

$$j = -\frac{a}{b} * i.$$

In another example, the measurement element of the manufactured object is a plane. If a scalar product of the initial vector of the probe **13** and a normal vector of the plane is less than 0, the ricochet vector of the probe **13** is equal to the normal vector of the plane. If the scalar product of the initial vector of the probe **13** and the normal vector of the plane is larger than 0, a magnitude of the ricochet vector of the probe **13** is equal to a magnitude of the normal vector of the plane, and a direction of the ricochet vector of the probe **13** is opposite to a direction of the normal vector of the plane.

In step S305, for each measurement point, the calculation module **230** calculates coordinates of a contact point of the manufactured object according to the coordinates of the center of the probe **13** and the ricochet vector of the probe **13**, and stores the coordinates of the contact point into the storage system **15**. The probe **13** contacts the manufactured object at the contact point when the CMM **12** performs automatic measurement of the manufactured object. In one embodiment, coordinates of the contact point of the manufactured object is calculated as follows: (x1, y1, z1)=(x0, y0, z0)−R× (a, b, c), where (x1, y1, z1) is the coordinates of the contact point of the manufactured object, (x0, y0, z0) is the coordinates of the center of the probe **13**, R is a radius of the probe **13**, and (a, b, c) is the ricochet vector of the probe **13**.

Although certain disclosed embodiments of the present disclosure have been specifically described, the present disclosure is not to be construed as being limited thereto. Various changes or modifications may be made to the present disclosure without departing from the scope and spirit of the present disclosure.

What is claimed is:

1. A method for determining ricochet vectors of a probe of a coordinate measuring machine (CMM) being executed by a processor of a computing device, the method comprising:

setting an approach distance between the probe and a manufactured object, and storing the approach distance into a storage system of the computing device;

obtaining coordinates of a center of the probe and an initial vector of the probe for each measurement point of the manufactured object when the probe is manually operated to measure the manufactured object;

fitting a measurement element of the manufactured object according to all measurement points of the manufactured object; and

for each measurement point, calculating an approach point of the manufactured object according to the approach distance and the initial vector of the probe, determining a position relation between the approach point and the measurement element of the manufactured object, calculating a ricochet vector of the probe according to the position relation, and storing the ricochet vector of the probe into the storage system.

2. The method of claim **1**, further comprising:

calculating coordinates of a contact point of the manufactured object for each measurement point according to the coordinates of the center of the probe and the ricochet vector of the probe, and storing the coordinates of the contact point into the storage system, wherein the probe contacts the manufactured object at the contact point when the CMM performs automatic measurement of the manufactured object.

3. The method of claim **1**, wherein a distance between the measurement point and a corresponding approach point is equal to the approach distance, and a direction from the corresponding approach point to the measurement point is in the same direction as a direction of a corresponding initial vector of the probe.

4. The method of claim **1**, wherein the coordinates of the center of the probe are obtained according to a focus position of an optical lens of a camera installed on the CMM.

5. The method of claim **1**, wherein a magnitude of the ricochet vector of the probe is 1.

6. A computing device, comprising:

a storage system;

at least one processor; and

a ricochet vector determination system comprising one or more programs that are stored in the storage system and executed by the at least one processor, the one or more programs comprising instructions to:

set an approach distance between a probe of a coordinate measuring machine (CMM) and a manufactured object, and store the approach distance into a storage system of the computing device;

obtain coordinates of a center of the probe and an initial vector of the probe for each measurement point of the manufactured object when the probe is manually operated to measure the manufactured object; fit a measurement element of the manufactured object according to all measurement points of the manufactured object; and

for each measurement point, calculate an approach point of the manufactured object according to the approach distance and the initial vector of the probe, determine a position relation between the approach point and the measurement element of the manufactured object, calculate a ricochet vector of the probe according to the position relation, and store the ricochet vector of the probe into the storage system.

7. The computing device of claim 6, wherein the one or more programs further comprise instructions to:

calculate coordinates of a contact point of the manufactured object for each measurement point according to the coordinates of the center of the probe and the ricochet vector of the probe, and store the coordinates of the contact point into the storage system, wherein the probe contacts with the manufactured object at the contact point when the CMM performs automatic measurement of the manufactured object.

8. The computing device of claim 7, wherein a distance between the measurement point and a corresponding approach point is equal to the approach distance, and a direction from the corresponding approach point to the measurement point is in the same direction as a direction of a corresponding initial vector of the probe.

9. The computing device of claim 6, wherein the coordinates of the center of the probe are obtained according to a focus position of an optical lens of a camera installed on the CMM.

10. The computing device of claim 6, wherein a magnitude of the ricochet vector of the probe is 1.

11. A non-transitory computer-readable storage medium storing a set of instructions, the set of instructions capable of being executed by a processor of a computing device to implement a method for determining ricochet vectors of a probe of a coordinate measuring machine (CMM), the method comprising:

setting an approach distance between the probe and a manufactured object, and storing the approach distance into a storage system of the computing device;

obtaining coordinates of a center of the probe and an initial vector of the probe for each measurement point of the manufactured object when the probe is manually operated to measure the manufactured object;

fitting a measurement element of the manufactured object according to all measurement points of the manufactured object; and

for each measurement point, calculating an approach point of the manufactured object according to the approach distance and the initial vector of the probe, determining a position relation between the approach point and the measurement element of the manufactured object, calculating a ricochet vector of the probe according to the position relation, and storing the ricochet vector of the probe into the storage system.

12. The storage medium of claim 11, wherein the method further comprises:

calculating coordinates of a contact point of the manufactured object for each measurement point according to the coordinates of the center of the probe and the ricochet vector of the probe, and storing the coordinates of the contact point into the storage system, wherein the probe contacts the manufactured object at the contact point when the CMM performs automatic measurement of the manufactured object.

13. The storage medium of claim 11, wherein a distance between the measurement point and a corresponding approach point is equal to the approach distance, and a direction from the corresponding approach point to the measurement point is in the same direction as a direction of a corresponding initial vector of the probe.

14. The storage medium of claim 11, wherein the coordinates of the center of the probe are obtained according to a focus position of an optical lens of a camera installed on the CMM.

15. The storage medium of claim 11, wherein a magnitude of the ricochet vector of the probe is 1.

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